

Current Status of $K^+ \rightarrow \pi^0 \mu^+ \nu_\mu \gamma$ study

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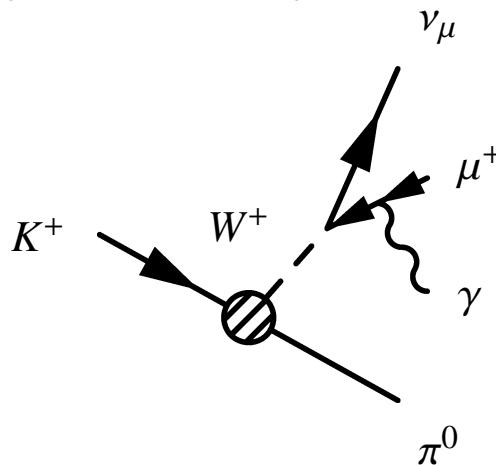
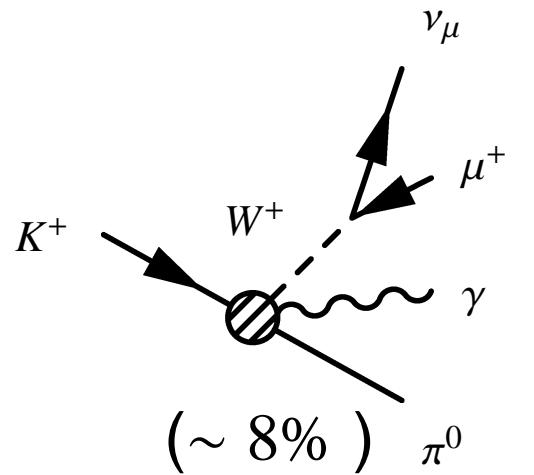
- ★ Physics motivations
- ★ Current Status of Data analysis
 - Background estimation
 - Acceptance estimation
- ★ Analysis schedule
- ★ Summary

Physics Motivations

Chiral Perturbation Theory

QCD effective theory in low energy region
quark field → pseudoscalar meson field

(using Only Chiral Symmetry)



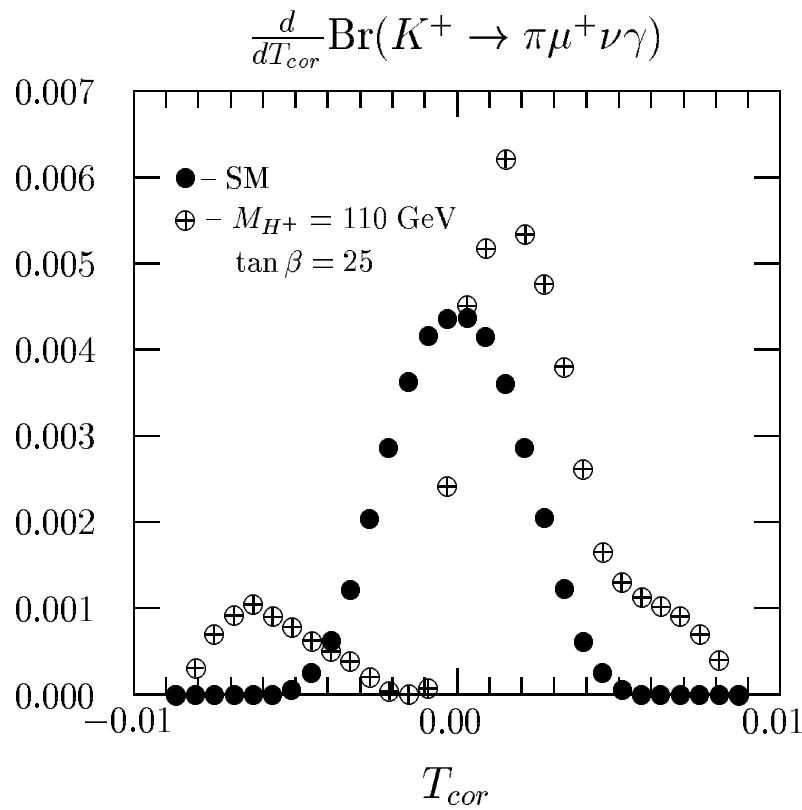
Structure Dependent

Branching ratio is predicted as $\sim 2.0 \times 10^{-5}$
($E_\gamma > 30 MeV, \theta_{\mu\gamma} > 20^\circ$)

Internal Bremsstrahlung

T-violation

asymmetry of $\underline{P_\pi \cdot (P_\mu \times P_\gamma)}$



$$T_{cor} = P_\pi \cdot (P_\mu \times P_\gamma) / m_K^3$$

(from hep-ex/0011033)

Experimental Status

Previous exp. @ Argonne National Laboratory (PR D8 1307([1973](#)))

No events were observed. :

$$BR < 6.1 \times 10^{-5} (CL = 90\%)$$

No observation yet!

Other $K_{l3\gamma}$ decays are already measured...

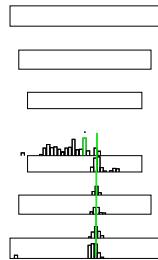
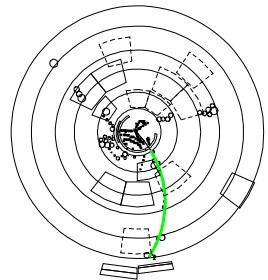
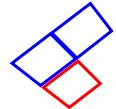
- ★ $K_{e3\gamma}^+ \dots (2.62 \pm 0.20) \times 10^{-4}$
- ★ $K_{e3\gamma}^0 \dots (3.62^{+0.26}_{-0.21}) \times 10^{-3}$
- ★ $K_{\mu3\gamma}^0 \dots (5.7^{+0.6}_{-0.7}) \times 10^{-4}$

Structure Dependent Term: NOT MEASURED!

Event Display

3Gamma

SCALE 1:16.0



RUN
EVENT

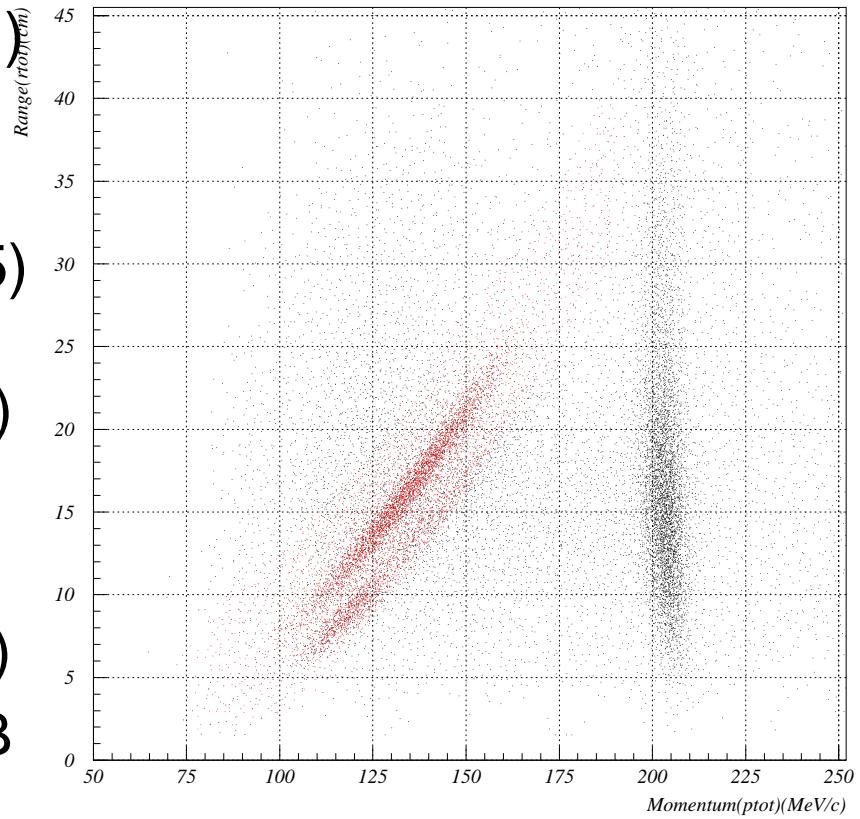
39415
426

- ★ 3 γ clusters in Barrel Veto
- ★ Right Stopping Counter
- ★ No Extra Activity

G3PASS1/G3PASS2

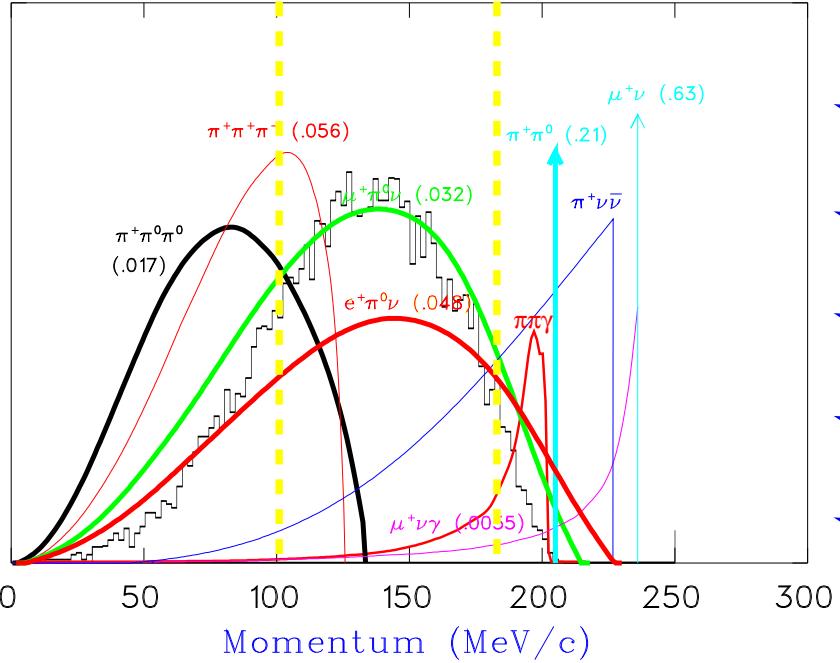
- ★ PASS1 (common to $K_{\mu 3\gamma}/K_{\pi 2\gamma}$ ana.)
 - Data Set: DLT * 35
 - Number of KB_LIVE: 1.86×10^{12}
(1.4 times larger than that of '95)
 - Data Reduction:
 $1\text{TB} \rightarrow 346\text{GB}(33.8\%)(\text{DLT}^*13)$

- ★ PASS2 (for $K_{\mu 3\gamma}$)
(not so tight for Background study)
 - Data Reduction: $346\text{GB} \rightarrow 60\text{GB}$

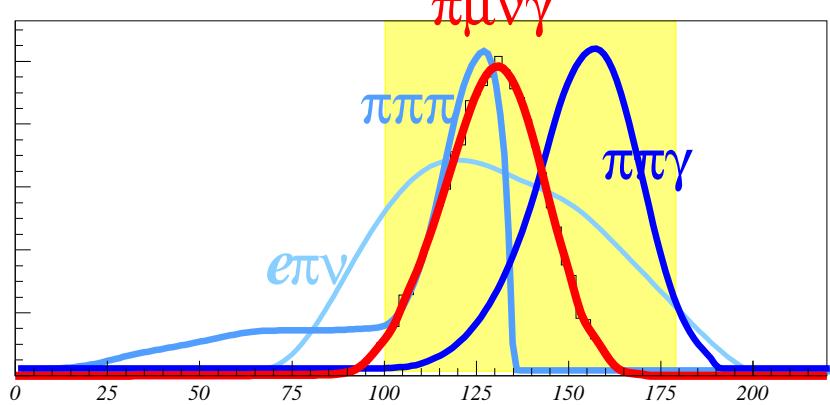


Backgrounds Sources

Arbitrary Units



(After 3gamma trigger) \Rightarrow



- ★ $\pi^0\mu^+\nu_\mu$ +accidental/splitted γ
- ★ $\pi^0e^+\nu_e$ +accidental/splitted γ
- ★ $\pi^+\pi^0\pi^0$ +missing/overlapping γ
- ★ $\pi^+\pi^0\gamma$
- ★ $\pi^+\pi^0$ +accidental/splitted γ

or

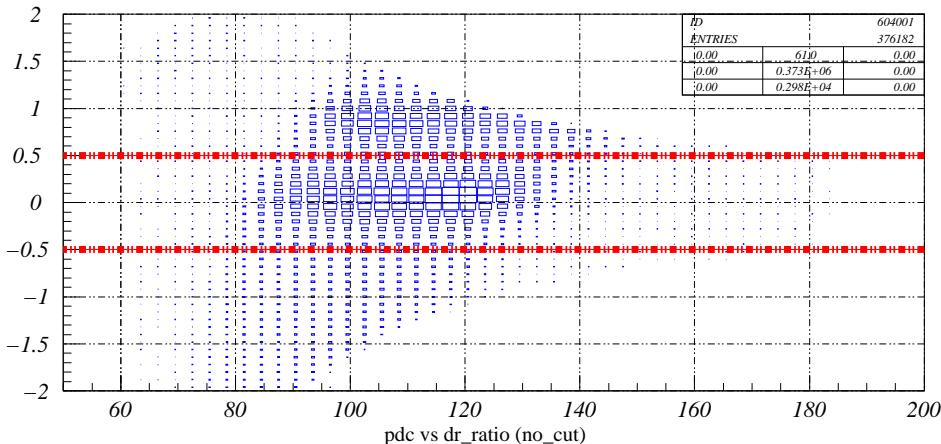
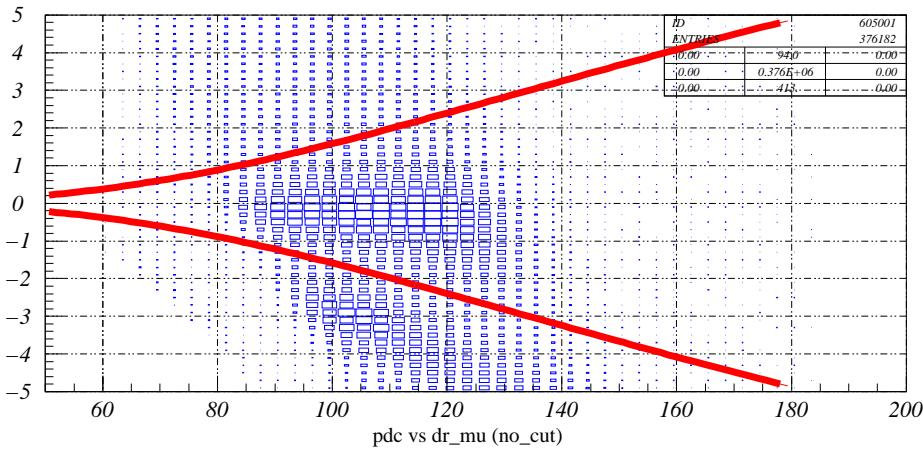
- ★ $4\gamma + 1\gamma$ is missed
and/or charged track miss-ID
- ★ $3\gamma +$ charged track miss-ID
- ★ $2\gamma +$ fake γ
and/or charged track miss-ID

Cuts Description

- ★ χ^2 cut by kinematical fitting($K_{\mu 3}$) $\chi^2_{K\mu 3\gamma}, \chi^2_{K\mu 3}$
- ★ Missing energy cut ($K_{\pi 2\gamma}$) $\Leftarrow K_{\mu 3\gamma}$ kinematic fitting
 - Minimum distance cluster cut
 - Three photon mass cut
- ★ overlapping photon cut($K_{\pi 3}$)
 - NG
 - PHI2G(-NG-Corrected)
 - TZMAX(-NG-Corrected)
- ★ extra γ cut (K_{e3})
- ★ dE/dx cut in RS(K_{e3})
- ★ opening angle($\theta_{\mu\gamma}$) cut

μ band cut

$dr_mu = R_{measured} - R_\mu$ $dr_mu = (R_{measured} - R_\mu)/(R_\pi - R_\mu)$
 $\Rightarrow \pi/\mu$ identification



kinematic fitting

13 Measured variables: $\mu, \gamma_1, \gamma_2, \gamma_3$

3 Unmeasured variables: ν

6 Constraints:

- ★ energy-momentum balance(4)
- ★ μ -track consistency(μ mass)(1)
- ★ π^0 invariant mass(1)

π^0 paring ...

- ★ highest χ^2 probability

$$\chi^2 = \sum (y_i - \eta_i) V_{ij}^{-1} (y_j - \eta_j)$$

where η_i is measured variables and y_i is fitted variables and V^{-1} is the inverse of error matrix

kinematic fit tuning

How to tune up signal kinfit without seeing signal?

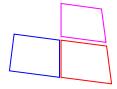
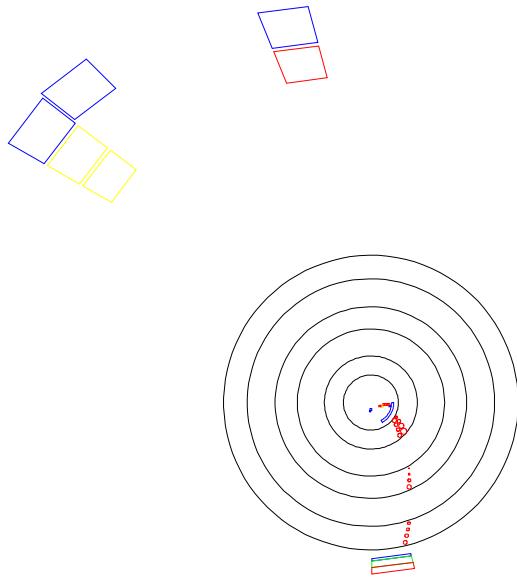
- ★ μ^+ related parameters $\Leftarrow K_{\mu 3}$ **kinfit**
 $K_{\mu 3}$ tagged by “muon band with off-timing γ ”
- ★ γ related parameters $\Leftarrow K_{\pi 3}$ **kinfit**
 $K_{\pi 3}$ tagged by “pion band with 4 γ ”

$\Rightarrow K_{\mu 3 \gamma}$ **kinfit**

extra γ cut

What happens about electron?

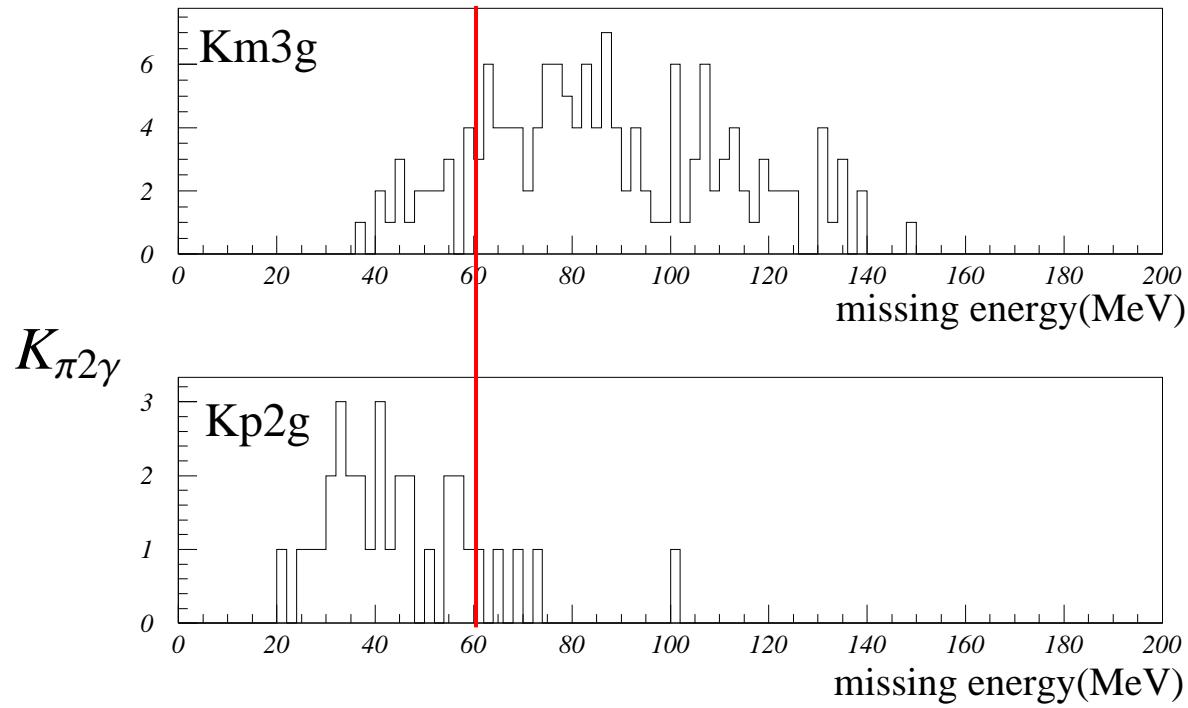
PNN(1) PNN(1) LO SCALE 1:16.0



RUN 97031
EVENT 76081

extra γ comes out as incomplete electron shower

missing energy cut



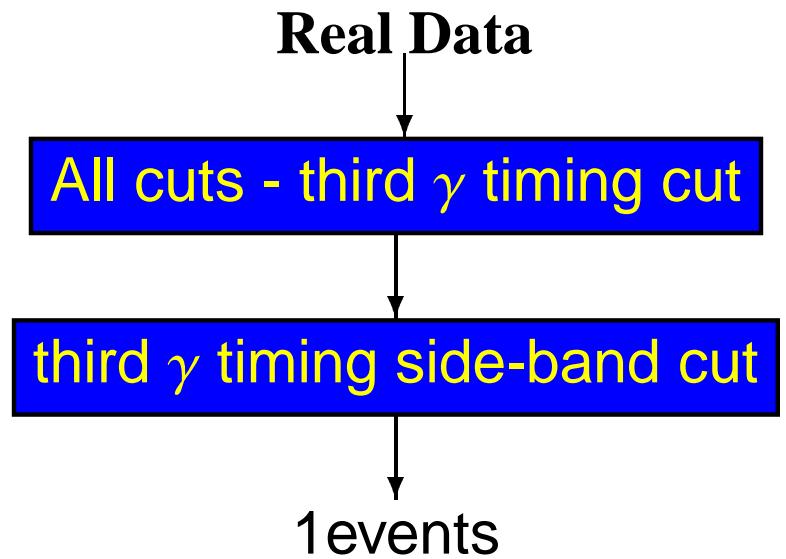
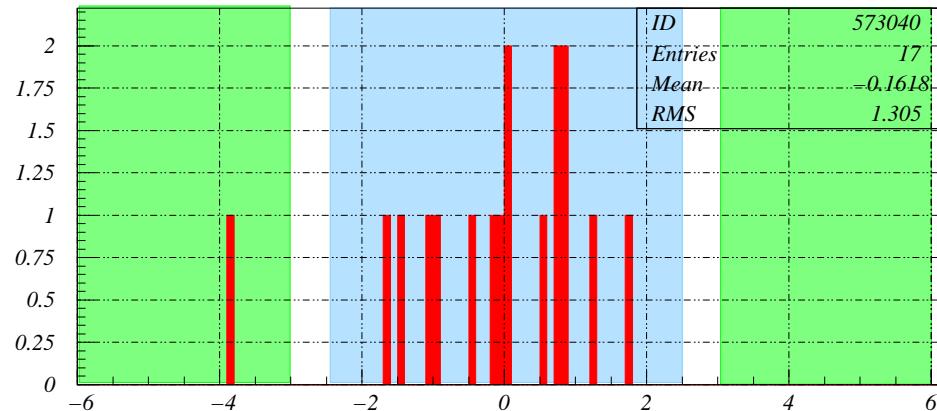
opening angle cut

$\cos(\theta_{\mu\gamma})$

- ★ suppress $K_{\pi 3}$ background
- ★ improve π^0 combination probability

Accidental γ Background

Using interpolation from side-band region in 3rd γ distribution

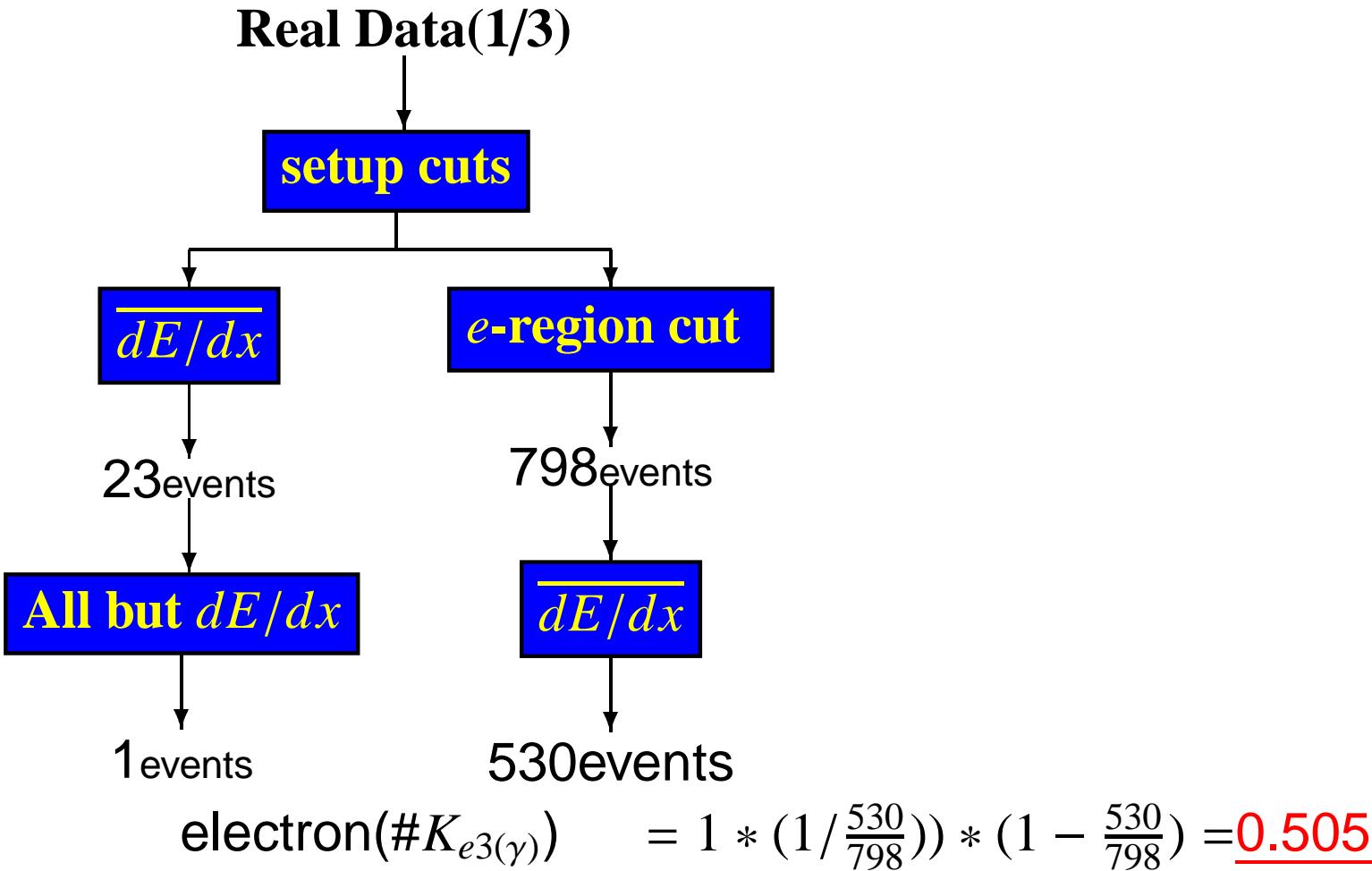


$$\# \text{Accidental background} = 1 \times 5/6 = \underline{0.83}$$

splitted γ Background

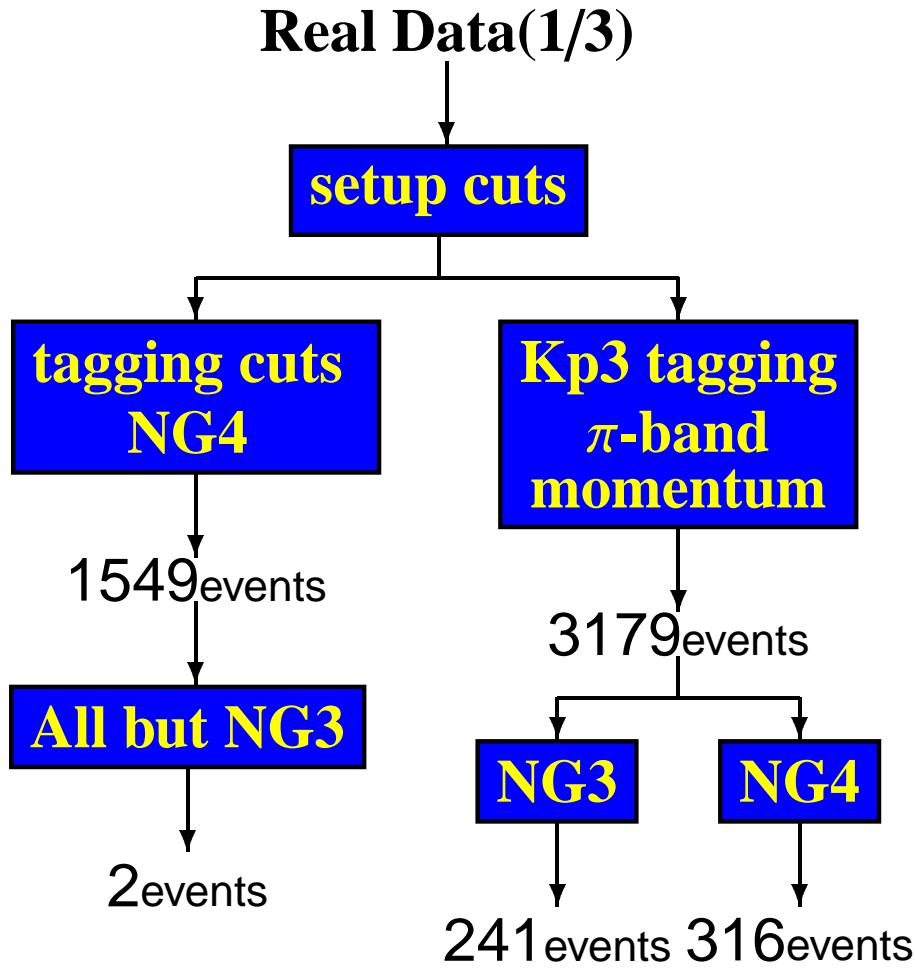
- ★ Minimum distance cluster cut
- ★ Three photon mass cut

electron Background



$K_{\pi 3}$ Background(BV-inefficiency)

Using Bifurcation techniques



$$\# \text{ of } K_{\pi 3}\text{-backgrounds} = 2 \times \frac{241}{316} = \underline{\textcolor{red}{1.52}}$$

$K_{\pi 3}$ bifurcation details

- ★ **setup cuts**

itgqualt,cos3d,beam quality cut,tgz, photon veto, $\frac{dE}{dx}$ cut

- ★ **tagging cuts(NG4)**

nreg=4 , γ cluster timing($t_{win} = 2.5\text{nsec}$) overlapping photon cut, splitted γ -cluster cut,extra γ cut

- ★ **All but NG3**

$\chi^2(K_{\mu 3}), \chi^2(K_{\mu 3\gamma})$, μ -band cut, missing energy cut

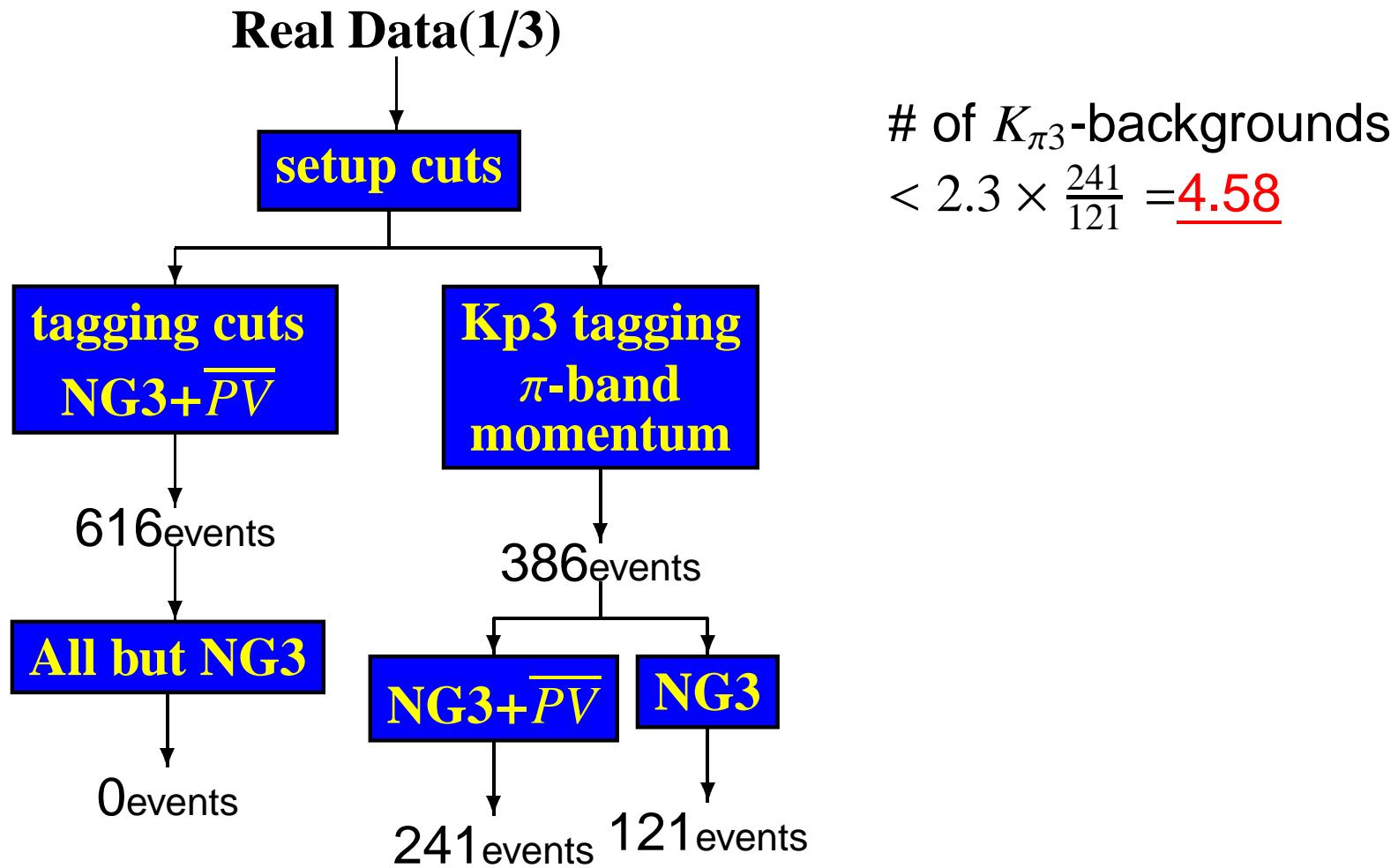
- ★ **Kp3 tagging**

π -band(on *rrs-pdc* plane), $100.<\text{ptot}<115.$

- ★ **NG3**

nreg=3,overlapping photon cut,splitted γ -cluster cut,extra γ cut, γ cluster timing

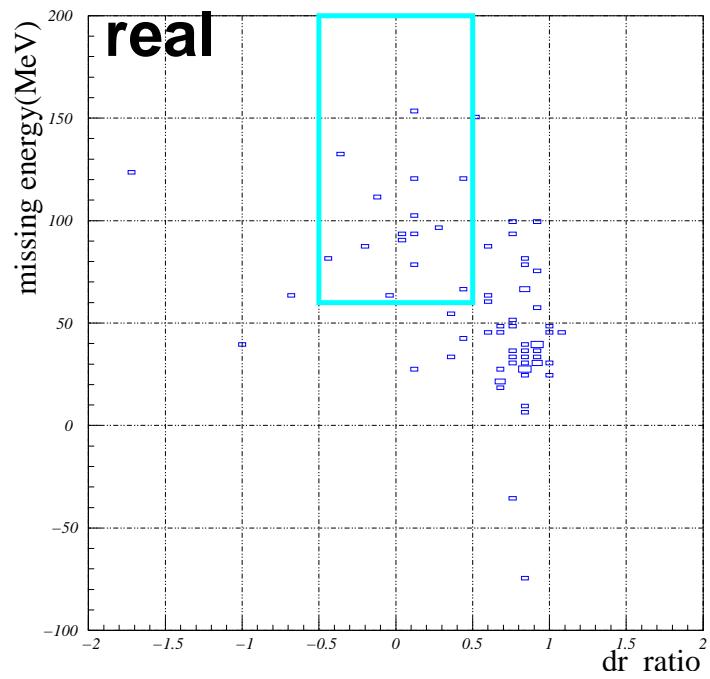
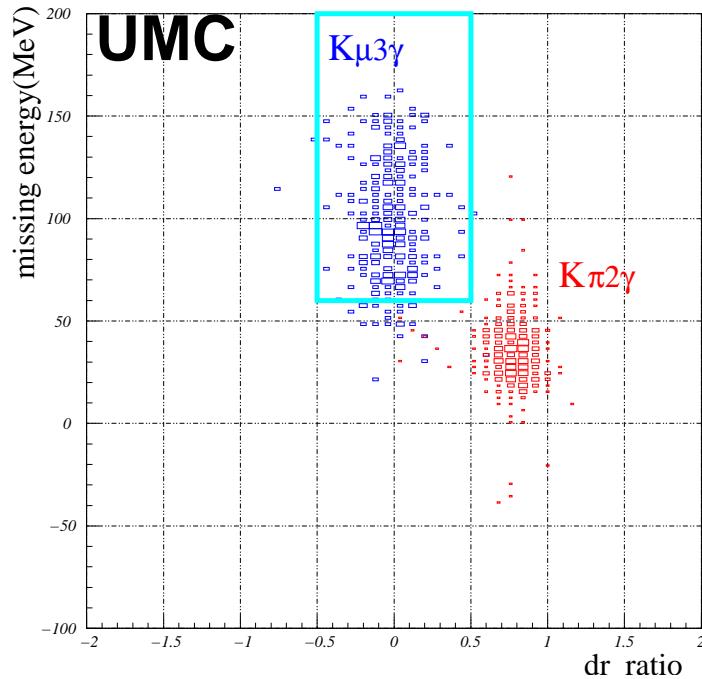
$K_{\pi 3}$ Background(PV-inefficiency)



$K_{\pi 2\gamma}$ background estimation

(Bifurcation methods seems impossible. If $K_{\pi 2g}$ can be tagged with only the infomation from only 3gamma,it will be possible)

pure UMC-based estimation(using *corrected F_s*): <0.194(90%CL)



Background summary

From 1/3 sample study

sources	#events
$K_{\pi 3}$	1.52+ <4.58
$K_{\pi 2\gamma}$	<0.194?
$K_{\mu 3} + Acc$	0.803
$K_{\mu 3} + \text{splitted } \gamma$???
$K_{e3}/K_{e3\gamma}$	0.505
All Backgrounds	2.83 +< 4.9

Acceptance Study F_s

3 measurements are tried.

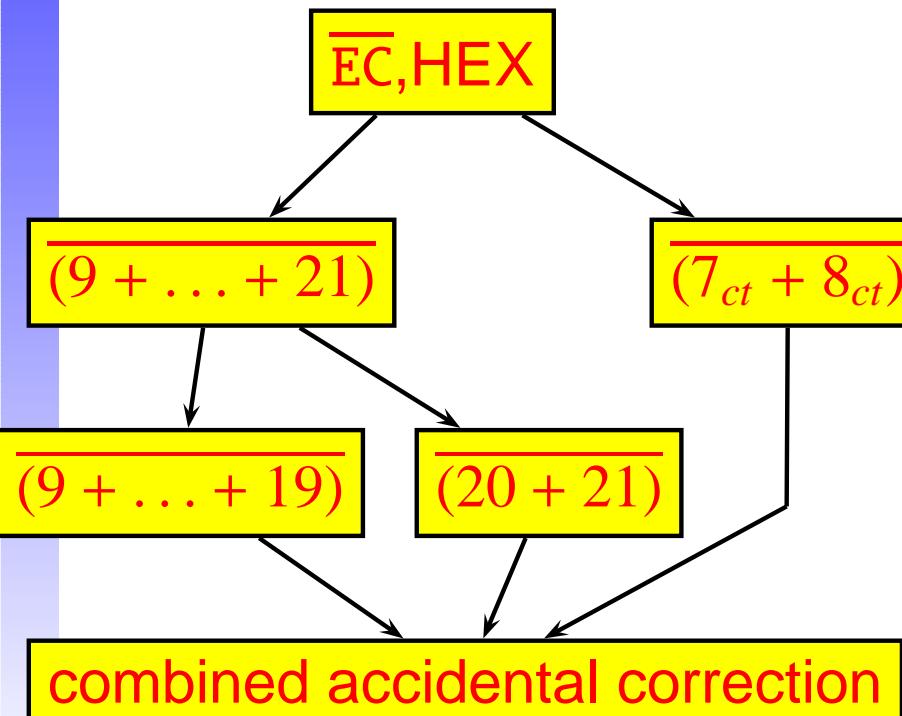
- ★ $K_{\pi 2}$ -based $F_s(Kp2(1))$ 0.740
- ★ $K_{\mu 2}$ -based $F_s(Km2(1))$ 0.719
- ★ $K_{\pi 3}$ -based $F_s(3\text{gamma})$ **0.273**

F_s from 3gamma data is quite different...

accidental loss correction(1)

Veto conditions must be corrected.

'98 3gamma trigger \equiv
 $KB \cdot DC \cdot T\bullet2 \cdot (3_{ct} + 4_{ct}) \cdot \overline{(7_{ct} + 8_{ct})} \cdot \overline{(9 + \dots + 21)} \cdot \overline{EC} \cdot HEX \cdot NG3$



$$\begin{aligned}\overline{EC}, HEX &\Leftarrow K_{\mu 2} \text{ in Kp2(1)} \\ &\Rightarrow 0.882 \\ \overline{(9 + \dots + 21)} &\text{ (direct estimation impossible)} \\ \overline{9 + \dots + 19} &\Leftarrow \pi\text{-scat} \\ &\Rightarrow 0.707 \\ \overline{20 + \dots + 21} &\Leftarrow K_{\mu 2} \text{ in Kp2(1)} \\ &\Rightarrow 0.965 \\ \overline{(7_{ct} + 8_{ct})} &\Leftarrow \text{offline analysis} \\ &\Rightarrow 0.991\end{aligned}$$

(combined accidental correction factor) = $0.601 \sim 0.623$

accidental loss correction(2)

$$\begin{aligned}\text{corrected } F_s &= 0.273 / (\text{accidental loss correction factor}) \\ &= 0.438 \sim 0.454\end{aligned}$$

After accidental correction, large discrepancy with
 $K_{\mu 2}$ -based/ $K_{\pi 2}$ -based F_s

unestimated factor?? or miss measurement in $K_{\pi 3}$ tagging??

Now choose 0.273 as *effective* F_s

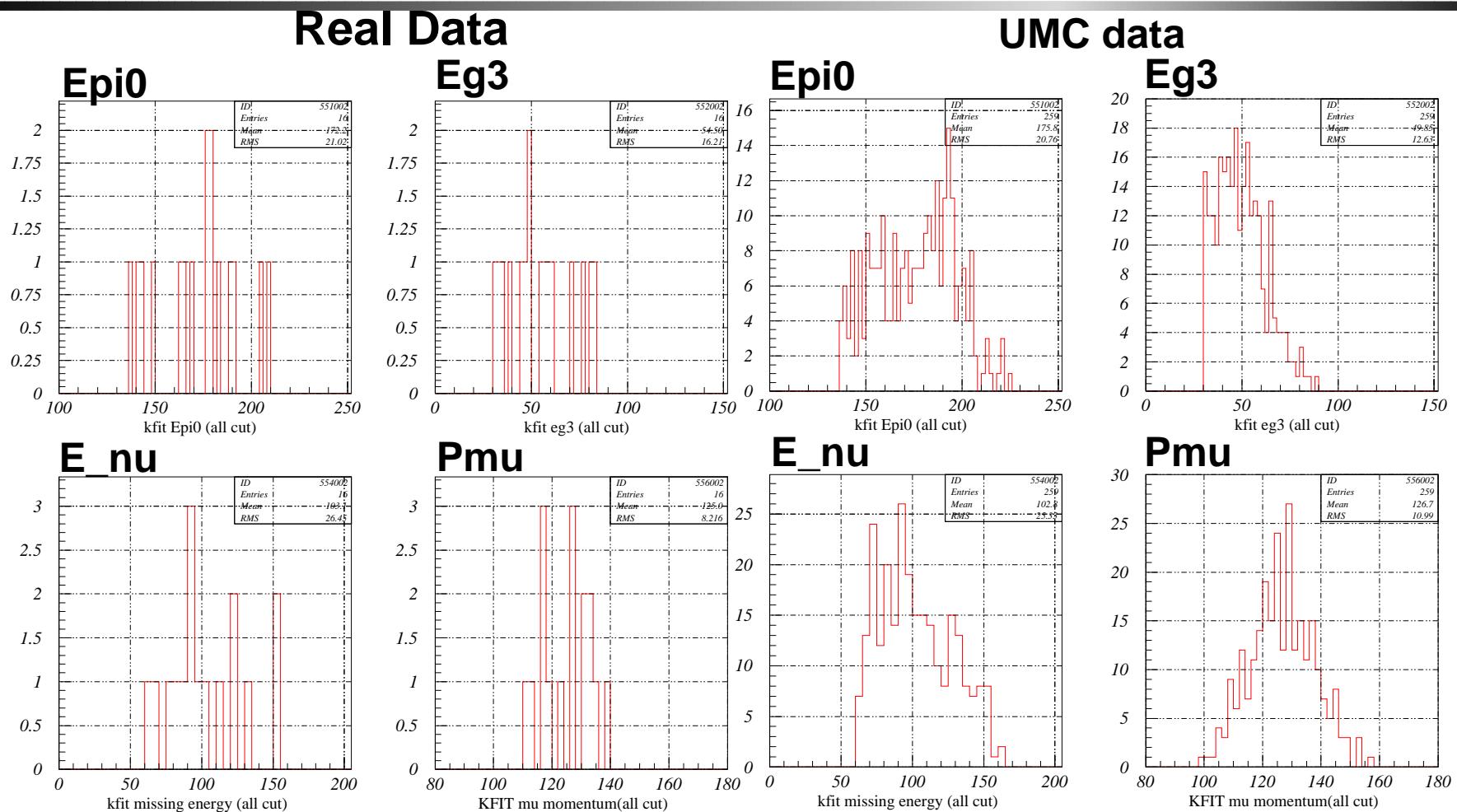
Expected Signals

$K_{\mu 3\gamma}$ acceptance for signal region: $\frac{259}{1.92 \times 10^7 \text{decays}} = 1.31 \times 10^{-5}$

1/3 samples

#ExpectedSignals(UMC) = KB_L \times Acceptance(UMC) \times Br \times F_s
= 14.7 events

Signal Candidates in 1/3 samples



Analysis schedule

Problems

- ★ F_s or correction factor uncertainty
- ★ some background estimations are still imperfect
- ★ cut position optimazition(S/N improvements)

these must be solved in a few month

Full(or 2/3) sample study

- ★ background estimation consistency check
- ★ Physics result

Summary

- ★ Estimated the number of possible backgrounds
- ★ Check the Prospects for $K^+ \rightarrow \pi^0 \mu^+ \nu_\mu \gamma$
 - ~ 50 events with about 20% background

TODO

- ★ Acceptance estimation is remained
- ★ Physics Results
 - Branching ratio
 - Structure Dependent
 - T-violation
 - etc...